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ELECTROPOLISHING AND/OR ELECTROPLATING APPARATUS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority of earlier filed provisional applications U.S. Application Nos. 60/372,542, entitled "MAINFRAMES FOR ELECTROPOLISHING AND/OR ELECTROPLATING AND/OR ELECTROPLATING ASSEMBLY," filed on April 14, 2002; No. 60/379,919, entitled "END EFFECTOR SEAL," filed on April 8, 2002; No. 60/370,955, entitled "METHOD AND APPARATUS FOR WAFER CLEANING," filed on April 8, 2002; No. 60/372,566, entitled "METHOD AND APPARATUS FOR ELECTROPOLISHING AND/OR ELECTROPLATING," filed on April 14, 2002; No. 60/370,956, entitled "METHOD AND APPARATUS FOR DELIVERING LIQUID," filed on April 8, 2002; No. 60/370,929 , entitled "METHOD AND APPARATUS FOR LEVELING WAFER," filed on April 8, 2002; No. 60/372,567, entitled "METHOD AND APPARATUS FOR ELECTROPOLISHING METAL FILM ON SUBSTRATE," filed on April 14, 2002; and No. 60/390,460, entitled "ELECTROPLATING APPARATUS," filed on June 21, 2002, all of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

1. Field:

[0002] This invention relates generally to semiconductor processing apparatus and methods, and more particularly to electropolishing and/or electroplating apparatus and methods for electropolishing and/or electroplating conductive layers on semiconductor devices.

2. Description of the Related Art:

[0003] Semiconductor devices are manufactured or fabricated on semiconductor wafers using a number of different processing steps to create transistor and interconnection elements. To electrically connect transistor terminals associated with the semiconductor wafer, conductive (e.g., metal) trenches, vias, and the like are formed in dielectric materials as part of the semiconductor device. The trenches and vias couple electrical signals and power between transistors, internal circuit of the semiconductor devices, and circuits external to the semiconductor device.

[0004] In forming the interconnection elements the semiconductor wafer may undergo, for example, masking, etching, and deposition processes to form the desired electronic circuitry of the semiconductor devices. In particular, multiple masking and etching steps can be performed to form a pattern of recessed areas in a dielectric layer on a semiconductor wafer that serve as trenches and vias for the interconnections. A deposition process may then be performed to deposit a metal layer

over the semiconductor wafer thereby depositing metal both in the trenches and vias and also on the non-recessed areas of the semiconductor wafer. To isolate the interconnections, such as patterned trenches and vias, the metal deposited on the non-recessed areas of the semiconductor wafer is removed.

[0005] Conventional methods of removing the metal film deposited on the non-recessed areas of the dielectric layer on the semiconductor wafer include, for example, chemical mechanical polishing (CMP). CMP methods are widely known and used in the semiconductor industry to polish and planarize the metal layer within the trenches and vias with the non-recessed areas of the dielectric layer to form interconnection lines.

[0006] CMP methods, however, may have deleterious effects on the underlying semiconductor structure because of the relatively strong mechanical forces involved. For example, as interconnection geometries move to 0.13 microns and below, there can exist a large difference between the mechanical properties of the conductive materials, for example copper and the low k films used in typical damascene processes. For instance, the Young Modulus of a low k dielectric film may be less than one tenth of the magnitude of copper. Consequently, the relatively strong mechanical force applied on the dielectric films and copper in a CMP process, among other things, can cause stress related defects on the semiconductor structure that include delamination, dishing, erosion, film lifting, scratching, or the like.

[0007] New processing apparatus and techniques are therefore desired to deposit and polish metal layer. For example, a metal layer may be removed or deposited from a wafer using an electropolishing or electroplating process. In general, in an electropolishing or electroplating process the portion of the wafer to be polished or plated is immersed within an electrolyte fluid solution and an electric charge is applied to the wafer. These conditions result in copper being deposited or removed from the wafer depending on the relative charge applied to the wafer.

BRIEF SUMMARY OF THE INVENTION

[0008] One aspect of the present invention relates to an exemplary apparatus and method for electropolishing and/or electroplating a conductive film on a wafer. The exemplary apparatus includes various processing modules such as cleaning modules, processing modules, alignment modules, as well as various apparatus for carrying out the processes of the difference modules such as robotics, end effectors, liquid delivery systems, and the like.

[0009] Another aspect of the present invention includes various apparatus and processing methods. One exemplary apparatus includes a cleaning module having a wafer edge clean assembly to remove metal residue on the bevel or outer portion of a major surface of a wafer. The edge cleaning apparatus includes a nozzle head configured to supply a liquid and a gas to a major surface of the wafer. The nozzle supplies the liquid in a region adjacent an outer edge of the major

surface of the wafer, and supplies the gas radially inward relative to the location the liquid is supplied. Directing the gas to the wafer surface at a location radially inward of the location the liquid is supplied may reduce the potential of the liquid flowing radially inward on the wafer to a metal layer formed thereon.

[0010] The present invention is better understood upon consideration of the detailed description below in conjunction with the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] **Fig. 1** illustrates an exemplary semiconductor processing assembly that may be used to electropolish and/or electroplate semiconductor wafers;

[0012] **Fig. 2** illustrates a robot including an exemplary end effector for transferring semiconductor wafers;

[0013] **Fig. 3** illustrates a plan view of an exemplary end effector;

[0014] **Figs. 4A** and **4B** illustrate plan and cross-sectional views of an exemplary end effector;

[0015] **Fig. 5** illustrates a plan view of an exemplary end effector;

[0016] **Fig. 6** illustrates a plan view of an exemplary end effector;

[0017] **Fig. 7** illustrates a plan view of an exemplary end effector;

[0018] **Fig. 8** illustrates a side view of an exemplary vacuum cup;

[0019] **Fig. 9A** illustrates an exemplary cleaning chamber module with a dome cover;

[0020] **Fig. 9B** illustrates a partial interior view of a cleaning chamber module;

[0021] **Fig. 9C** illustrates an exploded view of cleaning chamber module with details of cleaning nozzles;

[0022] **Figs. 10A** and **10B** illustrate a top view and side view of an exemplary edge clean assembly;

[0023] **Figs. 11A – 11H** illustrate various views of an exemplary nozzle head included as a part of a bevel clean assembly;

[0024] **Fig. 12** illustrates an exploded view of an exemplary chuck motor assembly included as part of a cleaning chamber module;

[0025] **Fig. 13** illustrates an exploded view of a cleaning chamber window included in a cleaning chamber module;

[0026] **Fig. 14** illustrates an exploded view of an exemplary optical sensor included in a cleaning chamber module;

[0027] **Fig. 15** illustrates an exemplary method for determining proper placement of a wafer in a chuck;

[0028] **Figs. 16A-16C** and **17A-17C** illustrate exemplary wafer cleaning processes;

[0029] **Fig. 18** illustrates an exploded view of an exemplary process chamber assembly;

[0030] **Fig. 19** illustrates an exploded view of an exemplary process drive system, which may be included in the process chamber assembly embodied in **Fig. 18**;

[0031] **Fig. 20** illustrates an exemplary nozzle with an energy enhancement element;

[0032] **Fig. 21** illustrates an exploded view of an exemplary electroplating apparatus;

[0033] **Fig. 22** illustrates an exploded view of the exemplary plating shower head assembly shown in **Fig. 21**;

[0034] **Fig. 23** illustrates an exploded view of an exemplary plating shower head for 300 mm wafers;

[0035] **Fig. 24** illustrates an exploded view of an exemplary plating shower head for 200 mm wafers;

[0036] **Figs. 25A-25E** illustrate various views of the shower head shown in **Figs. 22 – 24**;

[0037] **Figs. 26A** and **26B** illustrate a top view and cross-sectional view of an exemplary leveling tool and wafer chuck;

[0038] **Fig. 26C** illustrates a cross-sectional view of an exemplary sensor shown in **Figs. 26A** and **26B**; and

[0039] **Fig. 27** illustrates an exemplary view of a software panel for a leveling tool.

DETAILED DESCRIPTION

[0040] In order to provide a more thorough understanding of the present invention, the following description sets forth numerous specific details, such as specific materials, parameters, and the like. It should be recognized, however, that the description is not intended as a limitation on the scope of the present invention, but is instead provided to enable a better description of the exemplary embodiments.

I. Exemplary Electropolishing and/or Electroplating Assembly:

[0041] A first aspect of the invention includes an exemplary electropolishing and/or electroplating assembly for processing semiconductor wafers. In one example, an apparatus for processing one or more semiconductor wafers may include a module for storing wafers, two or more vertically stacked processing modules for electropolishing the wafer or electroplating the wafer, a cleaning module, and a robot (with an end effector or the like) for transferring the wafer. The apparatus may be divided into two or more sections characterized by separate frames. In general the robot transfers the wafer between the module for storing the wafer, the processing module, and the cleaning module to perform a desired process on the wafer. Additionally, various other modules and features may be included for the processing of semiconductor wafers as will be described.

[0042] **Fig. 1** illustrates an exploded view of an exemplary electropolishing and/or electroplating assembly **100**. In this example, the assembly **100** includes a mainframe (backend, "BE") **108** and frontframe (factory interface, "FI") **132**; however, the assembly **100** may be divided into fewer or more sections.

[0043] The BE **108** may include an electrical chassis assembly **102**, cleaning drain/process exhaust **104**, cleaning module assembly **106**, AC control assembly **110**, liquid delivery system (LDS) **112**, gas control system (GCS) **114**, process drain **116**, pumps and surge suppressors **118**, cabinet exhaust **120**, process tank **122**, liquid filters **124**, liquid containment tray **126**, and double containment area **128**, process module assembly **130**.

[0044] The FI **132** may include a wafer pre-aligner **134**, front panels **136**, light tower **138**, robot frame assembly **140**, robot controller **142**, emergency machine off (EMO) button **144**, front opening unified pod (FOUP) **146**, and fan filter unit **152**.

[0045] Assembly **100** may be detached into two sections, i.e., the FI **132** and the BE **108**, allowing the two sections to be transported separately and be reassembled on site into a single unit. Furthermore, the robot frame assembly **140**, which can include robot assembly **147**, dry end effector **148**, wet end effector **149**, and robot controller **142**, may detach from and roll out of the FI **132** during transit or for maintenance, for example. Assembly **100** may therefore be modularized or divided into various sections to assist in transporting, cleaning, maintenance, and the like.

[0046] As shown in **Fig. 1**, FOUP **146** may include one or more pods for storing wafers. The dry end effector **148** transfers a wafer **150** from any one of the pods to the wafer pre-aligner **134**. The wafer pre-aligner **134** aligns wafer **150** before the wet end effector **149** retrieves the wafer and transfers it to the process module assembly **130**. It should be recognized that wafer **150** may be transported between modules by other methods and devices.

[0047] The process module assembly **130** may include one or more racks of electropolishing assemblies for polishing wafers, or electroplating assemblies for plating wafers **131**. The electropolishing assemblies or electroplating assemblies **131** may be stacked vertically to reduce the footprint of the process module assembly **130**. The cleaning module assembly **106** can include racks of cleaning chamber modules **107** for cleaning wafers. Similarly, cleaning chamber modules **107** may be stacked vertically. After wafer **150** has been processed for electropolishing or electroplating, the wet end effector **149** transfers wafer **150** to the cleaning chamber module **107**. Dry end effector **148** retrieves wafer **150** from cleaning chamber **107** and returns wafer **150** to its pod in FOUP **146**. Generally, the "dry" end effector **148** is used when retrieving wafer **150** from and returning to a pod in FOUP **146**, or from the cleaning chamber module **107**. The "wet" end effector **149** is generally used to retrieve wafer **150** after processing because wafer **150** may have residue from the processing. Limiting the retrieval of processed wafers with the wet end effector

149 will reduce the potential for cross contamination between dry end effector **148** and wet end effector **149** and the wafers they handle and transfer within assembly **100**.

[0048] An exemplary electropolishing assembly that may be used in conjunction with assembly **100** is described in PCT Patent Application No. PCT/US02/36567, entitled ELECTROPOLISHING ASSEMBLY AND METHODS FOR ELECTROPOLISHING CONDUCTIVE LAYERS, filed on November 13, 2002, which is incorporated in its entirety by reference herein.

[0049] As shown in **Fig. 1**, a majority of the electrical equipment is housed in the BE **108**, particularly, in electrical chassis assembly **102** and AC control assembly **110**. The LDS **112** and the GCS **114** are also located in the BE **108**.

[0050] The LDS **112** can include supply lines for DI water, and various chemical and/or electrolyte fluids, which may vary in composition depending on the particular application and processing modules included in assembly **100**. The GCS **114** may also include various control valves, sensors, and supply lines to control and monitor delivery of various chemicals and fluids.

[0051] Pumps and surge suppressors **118** pump the process liquid from the process tank **122** to process module assembly **130**. Liquid filters **124** may be included in the supply lines to filter the process liquid before it goes to the process module assembly **130**. After wafer **150** is processed, the process liquid may be drained into the process tank **122** through process drain **116**. Any gases, e.g., potentially harmful gases, from process module assembly **130** and cleaning module assembly **106** may be exhausted through process exhaust **104**. The cleaning drain/process exhaust **104** can also be used to release DI water or gas from the cleaning module assembly **106**. The cabinet exhaust **120** can be used to release gas generally present inside of the BE **108**. FI **132** may include a fan filter unit **152** to provide filtered clean air in FI **132**.

[0052] The BE **108** may also include liquid containment tray **126** and double containment area **128**. The liquid containment tray **126** can be useful in case of an overflow from the process tank **122**, or leaks in the supply lines. The liquid containment tray **126** may further include leak sensors to detect leaks. The double containment area **128** can contain leaks from supply lines that are already insulated by external tubing.

[0053] The supply lines, pumps and surge suppressors **118**, liquid filters **124**, liquid containment tray **126**, and double containment area **128** may generally include materials resistant to acid and corrosion.

[0054] BE **108**, FI **132**, and robot frame assembly **140** can be made of stainless steel, preferably grade 316 stainless steel. The robot assembly **147** can be made of aluminum, stainless steel, or the like. If robot assembly **147** includes aluminum or other materials susceptible to corrosion, the surface of the aluminum portions may be anodized and coated with Teflon or the like to protect them from corrosion. Cleaning module assembly **106** can be made of stainless steel, plastic, PVC, PVDF, polyurethane, Teflon, and the like, preferably grade 316 stainless steel. GCS **114** and liquid

containment tray **126** can be made of plastic materials, preferably non-flammable plastics. Process tank **122** can be made of plastics such as PVC, PVDF, Teflon, and the like, preferably PVDF. It should be recognized, however, that other suitable materials or coatings for use in BE **108** and/or FI **132** are contemplated.

[0055] An exemplary process for electropolishing or electroplating a semiconductor wafer begins with a pod containing wafers placed in FOUP **146**. The pod, or door to the pod, is opened to allow robot assembly **147** access therein to pick a wafer with end effector **148**. Robot assembly **147** and dry end effector **148** transfer wafer **150** to wafer pre-aligner **134** to align wafer **150** for processing. After wafer pre-aligner **134** aligns wafer **150**, robot assembly **147** picks up wafer **150** from wafer pre-aligner **134** using the wet end effector **149**, and transfers wafer **150** to electropolishing or electroplating assembly **131** for processing.

[0056] After the electropolishing or electroplating process is completed, robot assembly **147** picks up wafer **150** by using the wet end effector **149**, and moves the wafer into cleaning chamber module **107**. After the cleaning process is completed, dry end effector **148** picks up wafer **150** and transfers wafer **150** back to the pod in FOUP **146** for retrieval.

[0057] In another exemplary process including multiple wafers and multiple electropolishing or electroplating assemblies, the exemplary process described above may be applied to a first wafer as simultaneously similar steps are applied to a second wafer, a third wafer, etc.

[0058] Various components of assembly **100** will be described in greater detail below. Although the exemplary electropolishing and/or electroplating apparatus has been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

II. End Effector Seal

[0059] In one aspect of a semiconductor assembly, an exemplary end effector apparatus and method are described. End effectors are commonly used in wafer fabrication processes for transferring wafers, for example, from one processing module to another for further processing, cleaning, storage, and the like. An exemplary end effector according to one embodiment includes a vacuum cup seal to securely hold and transfer a semiconductor wafer. The exemplary end effector may be included within a semiconductor processing assembly, and more specifically, a robot assembly of a semiconductor assembly. The exemplary end effector may enable a more secure hold of a semiconductor wafer surface and in turn may transfer the wafer more accurately and reliably to its destination.

[0060] **Fig. 2** illustrates an exemplary robot assembly for transferring semiconductor wafers in a processing assembly. Robot assembly includes exemplary end effector **206** associated with the robot for picking up and transferring wafer **216**. End effector **206** creates a vacuum on the

underside of end effector **206** to secure wafer **216** thereto for transfers from one module to another. End effector **206** may place or release wafer **216** by eliminating the vacuum or increasing the pressure such that the force of gravity overcomes the seal and wafer **216** is released from end effector **206**. Additionally, end effector **206** may hold the underside of wafer **216** with a relatively smaller pressure than the environment to hold the wafer **216** thereto against vibration, acceleration during transfer, and the like.

[0061] **Fig. 3** illustrates one side of an exemplary end effector **306** in greater detail. As shown in **Fig. 3**, end effector **306** is coupled to a vacuum source controlled by vacuum valve **322** and with a pressured nitrogen source controlled by nitrogen valve **320**. When vacuum valve **322** is turned ON, the vacuum source is coupled to end effector **306** and will reduce the pressure in vacuum cup **302** to hold wafer **216** to end effector **306**. When vacuum valve **322** is turned OFF and nitrogen valve **320** is turned ON, end effector **306** will release wafer **216** from vacuum cup **302** as the pressure is increased within cup **302**.

[0062] It should be understood that an absolute or near absolute vacuum is not required; rather, a reduced pressure relative to the processing environment sufficient to hold and secure wafer **216** against gravity, vibrations, acceleration during transfer, and the like is sufficient. Further, gas other than nitrogen, for example, air or the like may be used to introduce gas and increase the pressure when releasing a wafer.

[0063] Nitrogen valve **320** may be left ON when a wafer is not being held or transferred to purge particles and/or prevent acid and the like from entering vacuum cup **302** or the vacuum passage within end effector **306** by maintaining the pressure near or greater than the surrounding environment pressure within vacuum cup **302**.

[0064] **Figs. 4A** and **4B** illustrate a plan view and cross-sectional view of one exemplary end effector **406**, which includes vacuum cup **402**, mushroom cap **404**, groove **405**, cut out portions **408** (to reduce weight of end effector), vacuum passage **412**, and screws **416** (for attachment to a robot or the like). End effector **406** may include any suitable material in its construction, such as stainless steel, aluminum, various alloys or metals, ceramics, plastics, and the like.

[0065] As shown in **Figs. 3** and **4A**, a vacuum source removes gas through vacuum passage **412** and aperture **414** located on a major side and near the distal end of end effector **406**. Vacuum passage **412** may be formed integral or within end effector **406** (as shown) or through a separate passage located adjacent to end effector **406**, e.g., on the opposite surface of end effector **406**.

[0066] With the vacuum or reduced pressure created in vacuum passage **412** a wafer positioned adjacent end effector **406** is pulled or forced compliant against the vacuum cup **402** to create a temporary seal between the opposing major surface of the wafer and the vacuum cup **402** of end effector **406**. Vacuum cup **402** may have any suitable shape such as elliptical, elongated circle, square, and the like. Vacuum cup **402** fits over the rim of a mushroom cap **404** and extends above

the surface of end effector **406**. Vacuum cup **402** may include an elastomer, silicon rubber, or other suitable material that is generally flexible or compliant to create a temporary seal with a wafer without causing damage to the wafer such as scratching or cracking.

[0067] As shown in **Figs. 4A – 4B**, a shallow groove **405** is formed across the mushroom cap **404** for increasing the hold of the vacuum, e.g., to prevent the wafer **416** from plugging aperture **414**. The groove **405** separates the top plane of mushroom cap **404** into two half circles. The shallow groove **405** may also be formed as a cross-hair shape, square, circle, or other suitable shape to improve suction and vacuum of end effector **406** and reduce the potential for aperture **414** from becoming blocked. Mushroom cap **404** may be made out of a similar material as end effector **406** such as metal or plastic. In one example, mushroom cap **404** is at a similar height as the distal end of end effector **406** (see **Fig. 4B**), such that as the wafer is pulled by vacuum cup **402** the wafer is pulled against the to distal ends and the mushroom cap **404**.

[0068] **Fig. 8** illustrates a cross-section view of a vacuum cup that may be included in an exemplary end effector. As shown in **Fig. 8**, the vacuum cup is generally a cavity formed on one surface of an end effector that may include a bottom portion **818** and sidewall **820** slanted generally at angle α. Angle α may vary between 0-180 degrees depending on the particular application, preferably between 5 and 50 degrees, and more preferably approximately 30 degrees. Sidewall **820** may extend to a height H above the surface of the end effector to be compliant and form a seal with a wafer. With additional reference to **Figs. 4A, 4B,** and **8**, end effector **406** will be positioned such that wafer **416** comes in contact with the edge of sidewall **820** as gas is drawn out from aperture **414** through the vacuum passage **410**. The vacuum cup **402** will pull and hold wafer **416** by the vacuum created in the cavity of vacuum cup **402**. The pressure difference will create a sufficient force to maintain a holding force on wafer **416** greater than the force of gravity on the wafer. To release wafer **1016** from the hold of end effector **406**, gas (e.g. nitrogen or the like) may be introduced through vacuum passage **410** and through aperture **414** to increase the pressure within the aperture **414** such that the holding force is overcome by gravity.

[0069] **Fig. 5** illustrates a plan view of another exemplary end effector **506**. End effector **506** illustrated in **Fig. 5** is similar to that of **Figs. 3, 4A, and 4B** except that end effector **506** includes three apertures **514** and three vacuum cups **502**. The apertures **514** and vacuum cups **502** may be located in various positions on the end effector **506**, depending on the design and particular application of the end effector **506**. Further, the shape of an end effector may include any suitable shape, such as horseshoe, rectangular, circular, pronged including one or more prongs, and the like.

[0070] **Fig. 6** illustrates a plan view of another exemplary end effector **606**. End effector **606** is similar to that of **Figs. 4A** and **4B** except that end effector **606** has a plurality of vacuum cups **602**, in this instance five vacuum cups **602**, each including an elongated (i.e., not circular) mushroom caps **604**. Further, end effector **606** includes a common vacuum passage positioned adjacent the

apertures **614** as opposed to **Fig. 5**, which includes vacuum passages branched apart for each separate aperture **514**.

[0071] **Fig. 7** illustrates a plan view of another exemplary end effector **706**. The end effector **706** of **Fig. 7** is similar to that of **Figs. 3A** and **3B** except that one vacuum cup **702** includes a plurality of apertures **714** therein. Vacuum cup **702** of this example, is shaped like a horseshoe, but with similar functionality as vacuum cup **402** and includes several elongated mushroom caps **704**, which are similar to the mushroom caps **604**.

[0072] Although the exemplary end effector seals have been described with respect to certain examples and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention. For example, various methods of creating a vacuum within the vacuum cup are contemplated as well as various other shapes and configurations of vacuum cups and mushroom caps to create seal when picking and transferring a wafer.

III. Method and Apparatus for Wafer Cleaning

[0073] In one exemplary aspect of a semiconductor assembly, an exemplary wafer cleaning method and apparatus are described. The exemplary wafer cleaning method and apparatus, may clean a wafer of debris or particles before an electropolishing or electroplating process as well as clean the wafer of processing liquid after an electropolishing or electroplating processing step. For example, after an electropolishing process the edge or outer region of the major surface of the wafer (often referred to as the "bevel region") may include copper residue. It is desirable to etch away this copper residue from the outer region and clean the wafer without damaging the thin metal layer in the inner region of the wafer. Therefore, in one aspect a cleaning module includes an edge clean assembly to remove metal residue on the outer or edge portion of a wafer. The edge cleaning apparatus includes a nozzle head configured to supply a liquid and a gas to a major surface of the wafer. The nozzle supplies the liquid in the edge region and supplies the gas at the inner edge of the edge to reduce the potential of the liquid flowing radially inward on the wafer to the metal film.

[0074] **Figs. 9A – 9C** illustrate various views of an exemplary cleaning chamber module for cleaning a wafer. As shown in **Figs. 9A – 9C**, the exemplary cleaning chamber module may include a dome cover **902**, cleaning chamber window **904**, cylinder cover **906**, leak sensor **908**, drip pan drain line **910**, base block **912**, drip pan clamp **914**, drip pan **916**, bottom chamber **918**, cutout for chuck motor assembly wiring **920**, two DI water nozzles **922** (backside) and **926** (top), two nitrogen nozzles **924** (backside) and **928** (top), edge clean assembly **930**, optical sensor **932**, nozzle for wafer front side chemical **934**, chuck **936**, drain plate **938**, top chamber **940**, exhaust and drain tube **942**, nitrogen line **944**, edge clean cover **946**, nozzle for wafer backside chemical **948**, and

chuck motor assembly **950**. In addition to the one nozzle for chemical **934**, a cleaning chamber module can include one or more nozzles for chemicals.

[0075] Wafer **901** may be positioned in the cleaning chamber by an end effector **903** or the like. When wafer **901** is determined to be in an acceptable position on chuck **936** for a cleaning process, the chuck motor assembly **950** can rotate chuck **936** and wafer **901** around the axis perpendicular to the major surfaces of the wafer. As chuck **936** and wafer **901** are rotating at a rotation speed of about 30 rpm, the DI water nozzles **922** and **926** can supply streams of DI water to the top and backside surfaces of wafer **901**. The DI water can flow past the edge of wafer **901** toward the wall of the cleaning chamber and drain through the drain plate **938** and into the exhaust and drain tube **942**. To remove the DI water from and to dry wafer **901**, the chuck motor assembly **950** may increase the rotation speed to 2,000 rpm, ± 1,000 rpm. The nitrogen nozzles **924** and **928** can then supply streams of nitrogen (or other suitable gas) to the top and backside of wafer **901** to further remove DI water from the top and backside of wafer **901**.

[0076] After wafer **901** is washed and dried and the chuck motor assembly **950** is stopped, the edge clean assembly **930** glides into position for edge cleaning. **Figs. 10A – 10B** illustrate an exemplary wafer edge clean assembly **930**, which may include DI water tube **1006**, rod **1010**, adapter rod **1008**, bracket **1012**, screws **1014**, air table cylinder **1016**, adjustable screw **1018**, flow regulator **1020**, compressed air tube **1022**, rod clamp **1024**, acid tube **1026**, nitrogen tube **1028**, nozzle head **1030**, rod wiper **1032**, nitrogen nozzle **1034**, and liquid nozzle **1036**. The length of the edge clean assembly **930** may be adjusted for use with 200mm wafer, 300 mm wafer, or other size by adding or removing adapter rod **1008**. The gap between the top of wafer **901** and the nitrogen nozzle **1034** can be in the range from 0.1 to 10 mm, and the liquid nozzle **1036** can be positioned above the edge area **1004**.

[0077] **Figs. 11A – 11C** illustrate plan, side, and front views respectively of exemplary nozzle head **1030** included with an edge clean assembly. As shown in **Figs. 11A – 11C**, nitrogen nozzle **1034** produces a nitrogen curtain **1102** of nitrogen gas near the edge of wafer **901**. In an exemplary edge cleaning process, wafer **901** may rotate at a rotation speed of approximately 50 ~ 500 rpm, preferably at 200 rpm. Liquid nozzle **1036** supplies a stream of chemical to form a thin layer of about 10 mm in width on the outer major surface of wafer **901** or edge area **1004**. The chemical removes the metal layer or metal residue, but the chemical may accidentally spread toward the center of wafer **901**, which may have deleterious effects on the metal layer. A variety of chemicals can be used to etch the metal residue in edge area **1004**. For instance, H_4SO_4 at 10% concentration and H_2O_2 at 20% concentration can be used to etch copper metal from edge area **1004**. Also, for increasing etch rates, the chemical solution can be heated to the range of 25°C to 80°C.

[0078] To reduce the potential for the chemical spreading inward from the edge, nitrogen nozzle **1034** supplies or directs a stream of gas, e.g., nitrogen, to create nitrogen curtain **1102** at the inside

edge of the edge area **1004** to prevent or at least reduce the potential of the chemical from spreading toward the center of wafer **901**. After edge area **1004** is cleaned, liquid nozzle **1036** can supply liquid jet **1104** of DI water to dilute and/or rinse off the chemical from wafer **901** at the edge area **1004**. Additionally, in one example, after the edge cleaning process an additional DI water wash may be performed by using DI water nozzles **922** and **926** to clean the top and backside of wafer **901**.

[0079] When the edge cleaning process is finished, chuck motor assembly **950** can stop rotating chuck **936** and wafer **901**, and edge clean assembly **930** can glide back from the edge cleaning position to a rest position.

[0080] **Figs. 11D – 11E** illustrate various views of another exemplary nozzle head **1030**. The example in **Figs. 11D – 11E** are similar to that of **Figs. 11A – 11C** except that the nitrogen nozzle **1034** has a horizontal span **1034h** extended from the nozzle. The horizontal span **1034h** may create a nitrogen curtain **3002** that more effectively prevents chemicals from edge nozzle **1036** from spreading towards the center of wafer **901**. The distance between the horizontal span **1034h** and wafer **901** surface is preferably in the range of approximately 0.1mm to 3.0mm, and more preferably approximately 1.5 mm.

[0081] **Figs. 11F –11G** illustrate various views of another exemplary nozzle head **1030**. The example in **Figs. 11F – 11G** is similar to that of **Figs. 11D – 11E** except that the horizontal span **1034h** is extended from both sides of the lower portion of the nozzle.

[0082] **Fig. 11H** illustrates another exemplary nozzle head **1030**. The example in **Fig. 11H** is similar to that of **Figs. 11A – 11C** except that it has two liquid nozzles **1036**, one for chemical and another for DI water. Separate nozzles may provide improved performance during a DI water rinse, for example.

[0083] **Fig. 12** illustrates an exemplary chuck motor assembly **950** that may be included in the wafer cleaning apparatus. In this example, chuck motor assembly **950** includes chuck **936**, top motor plate **1202**, optical sensor **1204**, shaft sleeve **1206**, motor **1208**, flag **1210**, spacer **1212**, centrifugal block shaft **1214**, centrifugal block **1216**, and plug **1218**.

[0084] With reference again to **Figs. 9A, 9B** and **10A**, to place a wafer **901** on chuck **936** an end effector **903** takes wafer **901** from a process chamber or the pre-aligner (see **Fig. 1**) and moves it to the cleaning chamber module through the cleaning chamber window **904** for cleaning. **Fig. 13** illustrates an exemplary cleaning chamber window **904** that includes inner plate **1302**, outer plate **1304**, bracket **1306**, flow controller **1308**, cylinder **1310**, cylinder cover **906**, and limit sensor **1312**. The end effector **903** loads wafer **901** in chuck **936**. The cylinder **1310** can raise the outer plate **1304** and close the cleaning chamber window **904** to begin a wafer cleaning process.

[0085] As shown in **Fig. 12**, exemplary chuck **936** includes base **1220** and three positioners **1222**. Chuck **936** may be modified for 200mm wafer, 300 mm wafer, or any other wafer size.

When the end effector **903** loads wafer **901** in chuck **936**, wafer **901** is positioned in the chuck **936** by the three positioners **1222**. With reference again to **Figs. 9A – 9C**, optical sensor **932** can detect the position of wafer **901** in chuck **936**. To check the error in wafer positioning, optical sensor **932** directs a beam to the top surface of wafer **901** as shown in **Fig. 15**. If end effector **903** positions wafer **901** on the top surface of a positioner **1222**, the beam will not fully reflect back to reflective sensor **932**. As chuck **936** rotates, the reflectivity may change accordingly. Furthermore, since the distance between wafer **901** and reflective sensor **932** changes, the difference or variance in the reflectivity may be used to verify if wafer **901** is placed accurately on chuck **936** and the three positioners **1222** or not. In one example, when wafer **901** is accurately positioned on chuck **936**, by the three positioners **1222**, the reflectivity is read between approximately 70 ~ 75 % while the chuck is rotating. However, when wafer **901** is not positioned accurately, the reflectivity is read between approximately 30 ~ 60%. A misplaced wafer might move out of chuck **936** when chuck **936** is rotating at high speeds, which may cause wafer **901** to break inside of the cleaning chamber module.

[0086] An exemplary optical sensor **932** is shown in **Fig. 14** and may include a fitting tube **1402**, fitting o-ring **1404**, reflective sensor **1406**, holder **1408**, viton o-ring **1410**, and holder flange **1412**. It should be recognized that other suitable optical sensors may be used to determine proper positioning of a wafer in relation to chuck **936**. In other examples, optical sensor **932** may be replaced by a non-optical sensor to measure the surface of a wafer such as a proximity sensor, eddy current sensor, acoustic sensor, and the like.

[0087] To prevent wafer **901** from spinning out of chuck **936** by the motion of relatively high centrifugal forces during various cleaning processes such as a drying cycle and the like, chuck positioner **1222** may include a centrifugal block **1216**. The centrifugal block **1216** can include a lower element (i.e., a weight) that is heavier than the top portion, which is approximate to the centrifugal block shaft **1214**. When chuck **936** is rotating at a rotation speed of about 1,000 rpm or higher, the centrifugal force will cause the weights in centrifugal blocks **1216** to rotate outward. Consequently, the upper portion of centrifugal block **1216** moves inward to hold and secure wafer **901** to chuck **936**. The weight, length, and the like of positioner **1222** and centrifugal block **1216** may be varied to change the speed at which the positioner **1222** moves to secure the wafer. When the chuck motor assembly **950** decelerates or stops, centrifugal block **1216** will return to its upright position due to reduced or zero centrifugal force. In order to secure the wafer, the chuck rotation speed is set in the range of approximately 200 ~ 3,000 rpm, preferably at 2,000 rpm.

[0088] **Figs. 16A-16C** illustrate an exemplary backside wafer cleaning process and the wafer in relation to positioners **1222** and wafer backside chemical **948**. In an exemplary wafer backside cleaning process, motor **1208** oscillates chuck **936** to face the nozzle for wafer backside chemical **948** such that the chemicals can be delivered to the backside of wafer **901** without splashing the

three wafer positioners **1222**. Chemicals that contact wafer positioner **1222** may splash onto and chemically etch the top surface of wafer **901**, which may cause defects in the structures and devices formed on wafer **901**. The backside chemical **948** may be positioned between two positioners **1222** and oscillated between angles β and $-\beta$. The backside chemicals may cover an area of wafer **901** beyond angles β and $-\beta$ by directing backside chemical **948** off center by moving backside chemical **948** between angles $-\gamma$ and γ as illustrated in **Figs. 16A-16C**.

[0089] The chemical delivered by chemical **948** will reach the backside of wafer **901**, and the cleaning time can be in the range of 5 ~ 100 seconds, preferably in 10 seconds. The cleaning process is then repeated for each one-third of the backside of wafer **901**.

[0090] **Figs. 17A-17C** illustrate another exemplary backside wafer cleaning process. The process is similar to that described with reference to **Figs. 16A-16C** except that chuck **936** is continuously rotated and backside chemical **948** is pulsed or timed to be "on" between positioners **1222** and "off" when directed at positioners **1222**. Similar to **Figs. 16A-16C**, nozzle backside chemical **948** may oscillate $\pm\gamma$ during the process. As shown in **Figs. 17B** and **17C**, as chuck **936** rotates counter-clockwise backside chemical 948 directs liquid to the wafer until angle a_1 where it is turned off. Liquid is again directed to the backside of the wafer at angle a_2.

[0091] In another example, to clean the portion of the backside of wafer **901** in contact with positioner **1222**, motor **1208** will generate a rotational movement with a sufficient level of rotational acceleration such that wafer **901** will displace from its original position. Therefore, chemicals delivered by nozzle for wafer backside chemical **948** can reach the portion of the backside of wafer **901** that had been in contact with positioner **1222** before the rotational movement. After cleaning the entire surface of the backside of wafer **901**, DI water nozzle **922** will supply streams of DI water to rinse the chemicals on the backside of wafer **901**.

[0092] Wafer **901** can go through one final cleaning cycle. As chuck **936** and wafer **901** are rotating at a rotation speed of about 30 rpm, the DI water nozzles **922** and **926** can supply streams of DI water to the top and backside of wafer **901** simultaneously. To remove the DI water from and to dry wafer **901**, the chuck rotation speed can be increased to 2,000 rpm, ± 1,000 rpm. The nitrogen nozzles **924** and **928** can then supply streams of nitrogen to the top and backside of wafer **901** to remove DI water film from the top and backside of wafer **901**.

[0093] In light of the above description of exemplary apparatus and methods, exemplary cleaning recipes or sequences may proceed as follows.

[0094] Initiate Cleaning:

a. Home chuck.
b. Open outer plate **1302**.
c. Place wafer **901** on chuck **936**.
d. Close outer plate **1302**.

[0095] Front side Cleaning:

e. Rotate chuck **936** at speed of 10 to 100 rpm, preferably at 50 rpm.

f. Deliver DI water from DI water nozzle (top) **926** to the front side of wafer **901**.

g. Stop DI water from DI water nozzle (top) **926**, then increase chuck rotation speed to 1,000 ~ 2,000 rpm, preferably 2,000 rpm.

h. Deliver nitrogen from nitrogen nozzle (top) **928** to dry the top surface of wafer **901**.

i. Stop nitrogen stream and stop chuck rotation.

[0096] Edge Cleaning:

j. Move the edge cleaning assembly **930** from its rest position to edge cleaning position by powering the air tube cylinder **1016**.

k. Rotate wafer **901** at the rotation speed of 100 ~ 500 rpm, preferably at 350 rpm, deliver nitrogen from nitrogen nozzle **1034** through nitrogen tube **1028**.

l. Deliver edge cleaning chemical from liquid nozzle **1036** through acid tube **1026**.

m. After the metal on the edge area **1004** is etched away, stop delivering edge cleaning chemicals.

n. Deliver DI water from the liquid nozzle **1036** through DI water tube 2006.

o. After chemicals on edge area **1004** are rinsed away, stop DI water stream.

p. Deliver nitrogen from nitrogen nozzle **1034** through nitrogen tube **1028**.

q. Stop chuck rotation and move edge cleaning assembly **930** back to the rest position.

[0097] Backside Cleaning:

r. Move chuck **936** to backside cleaning position, i.e., the position where the distance between the nozzle for wafer backside chemical **948** and the two adjacent positioners **1222** is equal. Motor **1208** starts to oscillate chuck **936** around the nozzle for wafer backside chemical **948**. The oscillation angle should be less than 45° ± 5°. The nozzle for wafer backside chemical **948** then delivers chemicals to the backside of wafer **901**.

s. Repeat step ***r*** for the second and third sections of wafer **901**. Alternatively, wafer **901** may be rotated continuously in one direction and backside chemical **948** is pulsed avoid positioners 1222.

[0098] Shift Turn Cleaning:

t. To shift wafer **901** from its position by using high acceleration speed during a swift turn.

u. Repeat step ***s***.

v. Repeat steps ***s*** through ***u*** for the second one-third of wafer **901**.

w. Repeat steps ***s*** through ***u*** for the last one-third of wafer **901**.

x. Deliver DI water through DI water nozzle (backside) **922** to the backside of wafer **901** and to the front side of wafer **901** through DI water nozzle (top) **926**, with wafer rotating at a rotation speed of about 50 rpm.

y. Stop delivering stream of DI water. Rotate chuck **936** at a rotation speed of about 1,000 ~ 3,000 rpm, preferably at 2,000 rpm, then deliver nitrogen to both front side and backside of wafer **901**.

z. Stop delivering stream of nitrogen and stop chuck **936**. Open the cleaning chamber window **904** by lowering the outer plate **1304** with cylinder **1310**. End effector **903** will then pick up wafer **901** and move said wafer to the storing pod (not shown).

[0099] The above sequence describes one exemplary recipe for wafer cleaning and is not intended to be limiting. There are various alternative methods to clean wafer **901** in accordance with other various aspects of the present invention. For example, a second exemplary recipe includes following steps *a* through *d* as described above to initiate the cleaning process, followed by steps *j* through *q* for edge cleaning, and finishing with steps *e* through *i* to clean and dry the front side with DI water and nitrogen gas.

[00100] Another exemplary recipe includes: following steps *a* through *d* as described above to initiate the cleaning process; followed by steps *j* through *q* for edge cleaning; continuing with steps *r* and *s* to clean the backside with chemical; steps *e* through *i* to clean and dry the front side using DI water and nitrogen gas; and steps *t* through *z* to clean and dry the backside with DI water and nitrogen gas. Additionally, during a backside cleaning process, DI water may be supplied to the top of the wafer to protect the top surface from any of the chemical used during the backside etch. Accordingly, it should be apparent to those skilled in the art that various processes are contemplated for cleaning semiconductor wafers with the exemplary apparatus and methods.

[00101] Although the apparatus and methods for cleaning wafers have been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

IV. Process Chamber

[00102] In another aspect of a semiconductor assembly, a processing chamber is included for electropolishing and/or electroplating semiconductor wafers. The exemplary processing chamber is interchangeable with electropolishing apparatus and electroplating apparatus.

[00103] In one exemplary process, a wafer is rotated while a stream of process fluid is directed to a relatively small portion of a major surface of the wafer. A nozzle or the like directing the stream of fluid is translated along a linear direction parallel to the major surface of the wafer, e.g., from the inner to outer radius of the wafer. To increase the uniformity of plating or polishing a metal layer on the wafer, the rotation of the wafer may be varied to create a constant linear velocity of the wafer surface with respect to the incident stream of fluid. Additionally, various exemplary methods for determining a thin film profile and electropolishing or electroplating process are described.

[00104] **Fig. 18** includes an exploded view of an exemplary process chamber assembly according to one embodiment. Exemplary process chamber assembly can include dynamic shroud **1802**,

magnetic coupler **1804**, shaft **1806**, bracket for mounting shaft **1808**, splashguard **1810**, tube **1812**, chamber tray **1814**, bottom chamber **1816**, feed through for optical sensor **1818**, plugs **1820**, process chamber **1822**, manifold **1824**, nozzle plate **1826**, end point detector **1828**, nozzle block **1830**, side plate **1832**, chamber window **1834**, half moon chamber **1836**, gate chuck **1838**, and window cylinder **1840**.

[00105] The exemplary chambers may be used equally well for electropolishing and/or electroplating, but are described generally with regard to electropolishing processes. When using the present invention for electroplating, nozzle block **1830**, nozzle plate **1826**, manifold **1824** and dynamic shroud **1802** may also be used in an electropolishing process. Alternatively, they may be replaced with a concentric circle electroplating apparatus. An exemplary concentric circle electroplating apparatus is described in U.S. Patent No. 6,395,152, entitled METHODS AND APPARATUS FOR ELECTROPOLISHING METAL INTERCONNECTIONS ON SEMICONDUCTOR DEVICES, filed on July 2, 1999, and U.S. Patent No. 6,440,295, entitled METHODS AND APPARATUS FOR ELECTROPOLISHING METAL INTERCONNECTIONS ON SEMICONDUCTOR DEVICES, filed on February 4, 2000, both of which are incorporated in their entireties by reference herein. Further, exemplary electropolishing and electroplating processes are described in PCT Patent Application No. PCT/US02/36567, entitled ELECTROPOLISHING ASSEMBLY AND METHODS FOR ELECTROPOLISHING CONDUCTIVE LAYERS, filed on November 13, 2002, U.S. Patent No. 6,391,166, entitled PLATING APPARATUS AND METHOD, filed on January 15, 1999, and PCT Patent Application No. PCT/US99/15506, entitled METHODS AND APPARATUS FOR ELECTROPOLISHING METAL INTERCONNECTIONS ON SEMICONDEUCTOR DEVICES, filed on August 7, 1999, all of which are hereby incorporated by reference in their entirety.

[00106] Further, an exemplary end-point detector and methods are described in U.S. Patent No. 6,447,668 entitled METHODS AND APPARATUS FOR END-POINT DETECTION, filed on September 10, 2002, and is hereby incorporated by reference in its entirety.

[00107] As shown in **Fig. 19**, the power drive system, which can be included in the process chamber assembly, can include x-axis flag **1902**, x-axis drive assembly **1904**, coupling **1906**, motor **1908**, bracket for z-axis mount **1910**, theta drive belt and pulley **1912**, theta y-axis reflective sensor **1914**, x-axis sensor **1916**, theta mount **1918**, z-axis universal ball joints **1920**, z-drive table assembly **1922**, bracket for z-motion mount **1924**, theta motor **1926**, theta drive pulley **1928**, chuck assembly **1930**, lid back cover assembly **1932**, x-axis linear bearing **1934**, y-axis adjustment thumb screw **1936**, z-axis plate **1938**, top lid **1940**, z-axis linear bearings **1942**, shafts **1944**, x-axis magnet **1946**, magnetic disconnect plate **1948**, y-axis stage **1950**, magnets **1952**, and bracket for magnet mount **1954**.

[00108] An exemplary chuck assembly is described, e.g., in U.S. Patent No. 6,248,222 B1, entitled METHOD AND APPARATUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, filed on September 7, 1999, U.S. Patent Serial No. 09/800,990, entitled METHODS AND APPARATUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, filed on March 7, 2001, and U.S. Patent Serial No. 09/856,855, entitled METHODS AND APPARTUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, filed on May 21, 2001, all three of which are incorporated in their entireties by reference herein.

[00109] As shown in **Fig. 18**, the process chamber **1822** can include a dynamic shroud **1802** that translates with chuck assembly 1930 and a splashguard **1810** to contain process liquid or electrolyte fluid within the chamber area. An optical sensor cable can be installed through the feed-through **1818** for an optical sensor and end point detector **1828**, or other components such as sensors to detect leaks in the bottom chamber **1816** or the chamber tray **1814**. Additional plugs **1820** may be used for further feed-throughs.

[00110] The exemplary apparatus of **Figs. 18** and **19** includes magnets **1952** to connect to the x-axis drive magnet mount plate **1946**. The chuck assembly **1930** can move along the x-direction by gliding on shafts **1944** through the x-axis linear bearing **1934**. When the exemplary apparatus is not in operation, e.g., to change processing apparatus or during maintenance, the process drive system can undock from the process chamber assembly. Motor **1908** will rotate an internal screw in the x-axis drive assembly **1904** counterclockwise to move forward along the x-direction. The same or new process drive assembly may dock with the process chamber assembly in the same fashion. One example includes a safety measure such that if there is an object between the process drive system and the chamber, or something preventing the x-axis drive assembly **1904** from moving forward or backward, the magnets **1952** or **1946** will disengage from the x-axis disconnect plate **1948**. The x-axis drive **1904** and motor **1908** will not be able to move the chuck assembly and top lid further; at which point, the x-axis sensor **1916** will recognize the disengagement of x-axis from the rest of the process drive system and motor **1908** will power down.

[00111] During the installation or periodic maintenance of the exemplary apparatus, y-axis adjustment thumb-screw **1936** can adjust the position of chuck assembly **1930** over the dynamic shroud **1802** and nozzle plate **1826** along the y-direction.

[00112] With reference to both **Figs. 18** and **19**, when the exemplary process chamber is used in a process application, the process drive system will be docked in the process chamber assembly by connecting magnets **1952** on the process drive system to magnetic coupler **1804** on the process

chamber assembly. Window cylinder **1840** raises gate chuck **1838** from half moon chamber **1836** to create an opening in the chamber window **1834**. A robot (see **Fig. 1**) may transfer wafer **1801** from a pre-aligner (see **Fig. 1**) through the chamber window **1834**. Wafer **1801** is loaded into chuck assembly **1930** for an electropolishing and/or electroplating process.

[00113] To move chuck assembly **1930** from the load or home position to a position for electropolishing or electroplating, the motor in z-drive table assembly **1922** turns its internal shaft assembly to lower the z-axis plate **1938** from the top of the z-axis linear bearings **1942** until the gap between chuck assembly **1930** and the top of nozzle block **1830** is in the range of approximately 0.5 to 10 mm, and preferably 5 mm. Alternatively, if the exemplary process chamber is used for electroplating, the motor in z-drive table assembly **1922** can lower the z-axis plate **1938** from the top of the z-axis linear bearings **1942** until the gap between wafer **1801** on chuck assembly **1930** and the top of concentric circle apparatus is in the range of approximately 0.5 to 20 mm, and preferably 5 mm. After a first metal layer is plated on wafer **1801**, z-axis plate **1938** may move up incrementally in accordance with a process recipe for the wafer **1801** for additional plating.

[00114] To polish wafer **1801**, the exemplary process chamber removes copper from the plated copper wafer **1801** uniformly and incrementally by applying electrical current at a different current density for different locations on the wafer **1801**. The recipe for electrical current and flow of process liquid will be based on the profile of said wafer and other user-defined requirements depending on the particular application. User-defined requirements might include the number of runs for large removals, the use of larger or smaller nozzles, or thickness of the copper layers to remain on the wafers. Typically, a wafer measurement metrology tool measures the thickness profile of the copper plating on a sampling of wafers. The measurements will help generate a current ratio table that can include the current ratio to be used in the polishing process at a given set-point on the wafers. The data and the resulting ratio table create a metal film thickness profile, which can be further modified by user-defined requirements to formulate the profiled thickness of the wafers, and the recipe for electrical current density and flow rate during a polishing process.

[00115] The electrical current density applied to wafer **1801** may vary depending on the type of removals. For example, to remove a thick metal film on wafer **1801**, a higher current will generally be used. To remove a thin metal film a smaller current will generally be used to enable a more controlled and precise removal process.

[00116] An exemplary process, or recipe, for electropolishing a wafer including a relatively thick layer of metal will now be described. The exemplary recipe generally entails four or more steps of processing. First, a removal of a large portion of the thick layer of the metal, e.g., copper, is performed. Second, the end point detector **1828** measures the reflectivity of the remaining copper layer to determine set-points for further polishing at a given location on wafer **1801**. This process recalculates the film thickness profile based on the reflectivity readings. Third, the process removes

relatively thin layers of the copper in accordance with the new metal film thickness profile. Fourth, the end point detector **1828** measures the reflectivity of the copper layers to determine if wafer **1801** has been polished to the desired thickness and/or profile. The third and fourth processes may be repeated until wafer **1801** is polished to the desired thickness and/or profile.

[00117] It should be recognized, however, that if the end point detector **1828** determines that too much copper plating was removed from wafer **1801**, e.g., in the initial removal process, the present invention may include a electroplating process wherein certain areas on the surface of the wafer are re-plated with copper. The electroplating process can include a method of reversing the voltage for the nozzle in the nozzle block **1830** with a suitable electrolyte fluid such as $CuSO_4$ + H_4SO_4 +H_2O or the like. An exemplary electroplating apparatus and method is described in U.S. Patent No. 6,391,166 cited previously and incorporated herein.

[00118] Exemplary Process Recipe:

Step 1. In order to remove layers of copper on wafer **1801**, theta motor **1926** rotates chuck assembly **1930** in a constant linear velocity as the chuck assembly **1930** moves along the x-direction. The nozzle in nozzle block **1830** may direct process liquid to wafer **1801** at a constant flow rate. The rotation speed of theta motor **1926** can be in relation to the current density and the linear travel distance of rotating chuck assembly **1930**. The electrical current ratio that is being applied to wafer **1801** can also be based on the metal film thickness profile and user-defined requirements. The exemplary recipe can continuously extrapolate new current density between, and new linear velocity at, each data point on the linear travel of rotating chuck assembly **1930**. The recipe can be further recalculated using the new current ratio and linear velocity. Process drive system moves the chuck assembly **1930** back to the start position along the x-direction.

Step 2: End point detector **1828** measures the reflectivity of copper plated surface of wafer **1801**, as theta motor **1926** rotates chuck assembly **1930** again in a constant linear velocity as the chuck assembly moves back and forth along the x-direction. The present example records the reflectivity of wafer **1801** and the corresponding linear distance of the chuck assembly, at a user defined intervals. The present example extrapolates the new data into part of the metal film thickness profile.

Step 3. Repeat Step 1 except the current flow will be adjusted based upon the reflectivity of end point detector **1828** to wafer **1801** at a given wafer location of linear distance. A smaller nozzle in nozzle block **1830** can be used to achieve a more controlled polishing of the copper plated surface.

Step 4. Repeat Step 2. If the new reflectivity measurements from the end point detector **1828** are larger than a pre-set value, repeat Step 3.

[00119] During exemplary polishing processes, chuck assembly **1930** may be rotated in the following three modes:

[00120] 1) Constant linear velocity mode:

$$\dot{\vartheta} = \frac{C_1}{2\pi R} \tag{1}$$

Where, R is the horizontal distance between nozzle and wafer center,

C_1 is a constant, and

$\dot{\vartheta}$ is the rotation speed.

[00121] In practical control, R=0 gives infinite rotational speed; therefore, equation (1) can be expressed as follows:

$$\dot{\vartheta} = \frac{C_1}{2\pi\,(R + C_2)} \tag{2}$$

Where C_2 is a constant set according to the particular apparatus and application.

[00122] 2) Constant rotation speed mode:

$$\dot{\vartheta} = C_3 \tag{3}$$

Where C_3 is a constant set by process recipe.

[00123] 3) Constant centrifugal force mode:

$$\frac{V^2}{R} = C_4 = \text{Centrifugal force} \tag{4}$$

Where, V is the linear velocity, R is the horizontal distance between nozzle and wafer center, and C_4 is a constant set according to the particular apparatus and application.

[00124] Equation (4) can be rewritten by using $V = \dot{\vartheta} \cdot 2\pi R$

$$\dot{\vartheta} = \frac{\sqrt{C_4}}{2\pi\sqrt{R}} \tag{5}$$

Again, R=0 gives infinite rotational speed, $\dot{\vartheta}$, in practical, formula (5) can be written as:

$$\dot{\vartheta} = \frac{\sqrt{C_4}}{2\pi\sqrt{R + C_5}} \tag{6}$$

Where C_5 is a constant set according to the particular apparatus and application.

[00125] Horizontal direction or x-direction movement of chuck can be written as:

$$\dot{R} = \frac{C_6}{2\pi R} \tag{7}$$

Where $\dot{R}$ is the speed of chuck assembly **1930** in x-direction and R=0 gives infinite $\dot{R}$, in practical, formula (7) can be written as:

$$\dot{R} = \frac{C_6}{2\pi\,(R + C_7)} \tag{8}$$

Where C_7 is a constant set according to the particular apparatus and application.

[00126] Although **Figs. 18** and **19** show a process drive system in which the chuck assembly **1930** moves along the x-direction, it should be recognized that during a process the nozzle plate **1826** or both the chuck assembly **1930** and nozzle plate **1826** can move along the x-direction depending on the particular application.

[00127] **Fig. 20** shows an exemplary nozzle **2054** that may be included in the exemplary process chamber assembly. The exemplary nozzle **2054** includes an enhancement energy unit **2080** that may be attached or mechanically coupled to the nozzle **2054**. The enhancement energy unit **2080** may enhance the agitation of electrolyte fluid **2081** at the metal film **2004** surface to provide a higher polishing rate, better surface finishing, and quality.

[00128] In one exemplary nozzle **2054** the energy enhancement energy unit **2080** includes an ultrasonic or magnasonic transducer. Electrolyte fluid **2081** may be input from side inlet **5200** of nozzle **2054**. The frequency of an ultrasonic transducer may be in the range of 15 kHz to 100 Mega Hz to agitate the fluid. Ultrasonic transducer can be made of ferroelectric ceramics such as barium titanate ($LiTaO_3$), lead titanate, lead zirconate, and the like. The power of an ultrasonic transducer may be in the range of 0.01 to 1 W/cm^2.

[00129] In another example, the energy enhancement energy unit **2080** may include a laser. For the similar purpose as described above, a laser can be irradiated on the metal surface during an electropolishing process. The laser may be, e.g., a solid state laser such as ruby laser, Nd-glass laser, or Nd:YAG (yttrium aluminum garnet, $Y_3Al_5O_{12}$) laser, gas laser such as He-Ne laser, CO2 laser, HF laser, or the like. The average power of the laser may be in the range of 1 watt to 100 watt/cm^2 for continuous mode. In another example, the laser can be operated in pulse mode. The pulse mode laser power can be much higher than the average mode power as will be recognized by those skilled in the art.

[00130] The laser may also detect film thickness of the metal film on wafer **1004**. In this example, a laser directed to the metal film stimulates ultrasonic waves on metal film. The metal film **2004** thickness may be measured through the detected ultrasonic wave during an electropolishing process. The thickness of metal film **2004** may be used to control the polishing rate by changing the current, the nozzle speed in the radius direction, and the like.

[00131] In another example, the energy enhancement energy unit **2080** may include an infrared light source to anneal the metal film **2004** during a polishing process. The infrared light source can provide additional options to control surface temperature of the metal film during polishing. The power of the infrared source may be in the range of 1w to 100 w/cm^2. An infrared source may also

be used to anneal the metal film during a polishing process. The grain size and structure are very important for determining the copper interconnect electro-migration performance and resistivity. Because the temperature is a factor in determining the grain size and structure of the metal layer, an infrared sensor can also be used to detect a surface temperature of the metal film during a polishing process.

[00132] An infrared sensor may also be used to determine the temperature of metal film **2004**. Monitoring the temperatures allows adjustments of the temperature during a polishing process with varying infrared source power, changing the current density, and the like.

[00133] In another example, the energy enhancement energy unit **2080** may include a magnetic field to focus the polishing current on the metal film **2004** during a polishing process. Focusing the polishing current allows for increased control of the polishing rate profile of the nozzle, which is increasingly important for relatively large diameter nozzles. The magnetic field may be generated in the direction of electrolyte flow, i.e., vertical direction to the metal film surface. A magnet and electric magnet, superconductor coil driving magnet or the like may be used to create and focus the magnetic field.

[00134] It should be recognized that other energy sources such as ultraviolet, X-ray, microwave sources, and the like may also be used to enhance the performance of an electropolishing process as generally described above.

[00135] Although the exemplary chamber modules and processes have been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

V. Electroplating Apparatus and Process

[00136] In another aspect of a semiconductor assembly, an electroplating apparatus and method is included for electroplating semiconductor wafers. In a plating apparatus and process it is generally desired for process fluid to be distributed evenly over the surface of the wafer to plate a metal film of uniform thickness. In one exemplary process a shower head for plating apparatus is described that includes a filter block that impedes an immediate stream of electrolyte fluid and distributes the process fluid more uniformly through a channel of the shower head prior to emerging from the shower head. Distributing the fluid through the channel more uniformly leads to equal or nearly equal flow rates of electrolyte fluid from each orifice of the shower head assembly to increase the uniformity of the plating process.

[00137] **Fig. 21** illustrates an exploded view of an exemplary electroplating apparatus for plating semiconductor wafers **2102**. The electroplating apparatus can include half-moon chamber **2104**, stationary shroud **2106**, plating shower head assembly **2108**, exhaust **2110**, liquid inlets **2112**, electrolyte fit through **2114**, liquid fit through **2116**, chamber tray **2118**, bottom chamber window **2120**, bottom chamber **2122**, process chamber **2124**, chamber window **2126**, top lid assembly **2130**,

liquid inlet tubing **2132**, electrode cable **2134**, and shafts **2136**. Top lid assembly **2130** may be functionally similar to the exemplary top lid assembly previously discussed under the heading "Process Chamber." The stationary shroud **2106** covers the wafer chuck (not shown) to prevent electrolyte from splashing out of the chamber during the electroplating and spin dry process, for example.

[00138] As shown in **Fig. 21**, wafer **2102** is loaded into the electroplating apparatus through half moon chamber **2104** to the wafer chuck of top lid assembly **2130**. To plate copper on wafer **2102**, top lid assembly **2130** will lower wafer **2102** and position the wafer above the top of plating shower head assembly **2108**. In one exemplary process of plating, a first metal layer partial deposition is performed while the gap between wafer **2102** and plating shower head assembly **2108** is in a range of about 0.1 mm to about 10 mm, and preferably about 2 mm. Top lid assembly **2130** may raise wafer **2102** an additional 2 mm to 5 mm and a second layer deposition may be performed where a thicker layer of copper is deposited on the wafer.

[00139] Exemplary electroplating processes and sequences are described in U.S. Patent No. 6,391,166, entitled PLATING APPARATUS AND METHOD, filed on January 15, 1999, U.S. Patent Application Serial No. 09/837,902, entitled PLATING APPARATUS AND METHOD, filed on April 18, 2001, and U.S. Patent Application Serial No. 09/837,911, entitled PLATING APPARATUS AND METHOD, filed on April 18, 2001, the entire contents of which are incorporated herein by reference.

[00140] **Fig. 22** illustrates an exploded view of an exemplary shower head assembly **2108** for a plating process. Shower head assembly **2108** may include outer channel ring **2202**, shower head top **2204**, and shower head **2206**. **Figs. 23** and **24** illustrate exploded views of exemplary shower heads configured for electroplating 300 mm wafer and 200 mm wafer respectively. For use with 200 mm wafers, simply replace the 300 mm outer channel ring **2302** with the 200 mm outer channel ring **2402**, and the 300 mm shower head top **2304** with the 200 mm shower head top **2404**. Thus, shower head **2006** can be used for both 300 mm and 200 mm wafers. With reference to **Fig. 24**, as the size of wafer decreases from 300 mm to 200 mm, the shower head top **2404** may include fewer rings and the outer channel ring **2402** may be smaller in diameter. It should be recognized, however, that the exemplary shower head may be configured for any size wafer.

[00141] **Fig. 25A** illustrates an exploded view of an exemplary shower head. As shown in **Fig. 25A**, shower head **2206** may include electrode rings **2502**, nuts **2504**, electrode connectors **2506**, electrode outer connectors **2508**, small inlet flare fittings **2510**, inlet flare fittings **2512**, plate filter blocks **2514**, shower head base **2516**, filter spacers **2518**, and plate filter rings **2520**. Each electrode ring **2502** is fitted on top of a matching plate filter ring **2520** and locked into place on the shower head base **2516** by fastening the electrode of electrode ring **2502** with nuts **2504**, electrode connector **2506** and electrode outer connector **2508**. Each electrode is attached with an electrode

cable **2134** to electrode outer connector **2508** as shown in **Fig. 21**. Electrode ring **2502** can be made of anticorrosive metals or alloys, such as platinum, titanium coated with platinum, and the like. Shower head base **2516** will have channels for electrolyte flow from inlet flare fittings **2512** and from small inlet flare fittings **2510**.

[00142] As further seen in **Fig. 25A**, an inlet flare fitting **2512** can be larger than the width of a channel in shower head base **2516** and the inlet flare fittings cannot be fasten on the same position for all 7- or 10-rings. In order to fasten the inlet flare fittings to shower head base **2516** and to evenly distribute the tension and weight to the rings, every other small inlet flare fitting **2510** or inlet flare fitting **2512** and opposing filter block **2514** are positioned on an opposite half of the circle (not shown for filter blocks **2514**). Similar to inlet flare fitting **2512**, electrode ring **2502** fits over plate filter ring **2520** such that the electrode is positioned on the other half of the circle with every other electrode ring.

[00143] **Fig. 25B** illustrates an exploded view of a plate filter ring **2520** and plate filter block **2514** joined together by filter spacers **2518** to form a liquid flow block assembly, with an electrode ring **2502** fitting over the liquid flow block assembly. The exemplary liquid flow block assembly will be positioned above shower head base **2516** with an inlet flare fitting **2512** beneath and center of each plate filter block **2514** with an o-ring **2530** (not shown). Each plate filter ring **2520** has orifices **2522** with a narrow aperture in the center of each orifice. With reference now to both **Figs. 25A** and **25B**, as the liquid flow block assembly and an electrode ring **2502** are fastened to shower head base **2516**, a channel is formed between plate filter ring **2520** and the bottom of the shower head base. Electrolyte fluid will flow in from inlet flare fitting **2512**. The electrolyte stream will first hit the center of the plate filter block **2514** above the inlet and be distributed throughout the channel. As the electrolyte fluid rises in the channels, the electrolyte will flow out of orifice **2522** uniformly and reach the electrode rings **2502**. The electrolyte fluid passes the electrode ring **2502**, and flows uniformly to the surface of wafer **2102** through apertures **2524** in nozzle head **2004**.

[00144] **Fig. 25C** illustrates the relationship between orifices **2522** and the nozzle head's apertures **2524** on the bottom of shower head **2006**. As shown in **Fig. 25C** and **Fig. 22**, the shower head top **2004** is stacked over shower head **2006** such that the apertures **2524** are positioned in between two orifices **2522**. This staggered positioning allows the flow of electrolyte discussed in above to flow more uniformly through each recess on the liquid block flow assembly. As illustrated in the top view of the shower head in **Fig. 25D**, the apertures **2524** are disposed around the outer ring on shower head top **2204** (or **2304** or **2404**). These apertures **2524**, also inside of the enclosing rings on the shower head top **2204**, may be formed in any shape, such as circle, elongated, and the like depending on the particular application. With reference to **Fig. 24**, apertures **2524** may be formed in an elongated circular shape created by forming three round holes.

[00145] Without plate filter block **2514**, inlet flare fitting **2512** may deliver electrolyte directly through one or more apertures above the proximity of the inlet flare fitting, causing disproportionate distribution of electrolyte throughout the channel. Since electrolyte is flowing from one outlet, the liquid pressure of electrolyte can be difficult to control. Using the liquid flow block assembly, the exemplary apparatus may provide for better control of electrolyte for metal deposition, e.g., copper, because plate filter block **2514** will impede the immediate stream of electrolyte and distribute the electrolyte throughout the channel. Distributing the electrolyte throughout the channel allows equal or nearly equal volumes of electrolyte to flow out of each orifice **2522** on plate filter ring **2520**. As shown in **Fig. 25E**, electrolyte comes out of electrode outer connectors **2508**, through the shower head base **2516** and plate filter ring **2520**, then around the sides of electrode ring **2502** and flows out of the apertures **2524** on shower head top **2004**.

[00146] Although the exemplary shower head apparatus has been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

VI. Method and Apparatus for Leveling Wafer

[00147] According to another aspect, a method and apparatus for leveling a semiconductor wafer relative to a processing module such as an electropolishing or electroplating apparatus. Generally, while processing a wafer it is desired that the wafer be leveled such that the major surface of the wafer is generally parallel to a level surface of a processing chamber or tool. For example, aligning the wafer in the processing apparatus increases the uniformity of the polishing or plating processes.

[00148] **Figs. 26A** and **26B** show an exemplary leveling tool **2604** that may be used to measure the parallelism of wafer **2602** within ± 0.001 inch relative to the processing apparatus, e.g., a processing chamber. As shown in **Figs. 26A** and **26B**, the leveling apparatus generally includes leveling tool **2604**, ground line **2610**, signal lines **1612**, control system **2614**, and chuck **2616**.

[00149] An exemplary chuck is described in U.S. Patent No. 6,248,222 B1, entitled METHOD AND APPARATUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, filed on September 7, 1999, and U.S. Patent No. 6,495,007, entitled METHODS AND APPARATUS FOR HOLDING AND POSITIONING SEMICONDUCTOR WORKPIECES DURING ELECTROPOLISHING AND/OR ELECTROPLATING OF THE WORKPIECES, filed on March 7, 2001, both of which are incorporated in their entireties by reference herein.

[00150] With reference to **Figs. 26A** and **26B**, chuck **2616** holds wafer **2602** during a semiconductor electropolishing and/or electroplating process. In order to provide for a more uniform process of the electropolishing and/or electroplating process, wafer **2602** is positioned parallel or nearly parallel to processing chamber **2630**, and in particular with the plating head or

polishing nozzles (not shown) of the processing apparatus. Leveling tool **2604** may be positioned within the process chamber **2630** to provide increased alignment of the wafer **2602**.

[00151] Leveling tool **2604** may include three sensors **2606** and corresponding signal lines **2612**. When leveling tool **2604** is placed under chuck **2616** and the wafer **2602** is brought down to leveling tool **2604**, signal lines **2612** (through sensors **2606**) provide connection to the control system **2614** through a thin metal layer formed on the surface of the wafer **2602**. A ground line **2610** from control system **2614** is connected to the wafer **2602** metal layer. As sensors **2606** contact the thin metal layer a circuit is completed between the sensors **2606** and the ground line **2610** that may be measured by controller system **2614**.

[00152] Additionally, as shown in **Fig. 26B**, leveling tool **2604** may include supports **2608** for use in measuring the parallelism of wafer **2602** in chuck **2616** and the polishing nozzles as well as position the leveling tool **2604** near the surface of wafer **2602**.

[00153] **Fig. 26C** illustrates a cross-sectional view of an exemplary sensor **2606**. Sensor **2606** can include holder **2626**, set screws **2618**, pin adjustment **2620**, contact screw **2622**, and pin **2624**. Signal line **2602** is connected to sensor **2606** through contact screw **2622**. Holder **2626**, pin adjustment **2620**, and pin **2624** can be made of metals or alloys, such as stainless steel, titanium, tantalum, or gold.

[00154] In one exemplary process for measuring the alignment or parallelism of wafer **2602** in relation to the process tool, chuck **2616** descends toward leveling tool **2604** until the pin **2624** of one of sensors **2606** contacts the conductive surface of wafer **2602**. The contact completes an electrical circuit that includes signal line **2612**, ground line **2610**, and control system **2614**, and provides a signal to control system **2614**. The control system **2614** determines the distance from the original (home) position of chuck **2616** to the pin's position at the moment of the contact.

[00155] Chuck **2616** continues its descent until the second sensor **2606**, and the third sensor **2606** contact the surface of wafer **2602**. Corresponding distances for both sensor contacts are taken and the measurement process ends.

[00156] As shown in **Fig. 27**, the exemplary process may include a software interface, which displays the measured distance in the moment of contact for each sensor **2606**. The interface can also display the location of sensors **2606**. The smaller in the difference between a maximum and minimum distance of the measured distances the closer the wafer **2602** is to being aligned or in a parallel relationship. The data can be used to make adjustment to chuck **2616** and consequently, position of wafer **2602**. After the adjustment is made, the measurement cycle can be repeated until the difference between the maximum and minimum of the measured distances is within design specification such as $\pm$ 0.001 inch or the like depending on the particular application.

[00157] Although the exemplary wafer alignment methods and systems have been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

[00158] The above detailed description of various devices, methods, and systems is provided to illustrate exemplary embodiments and is not intended to be limiting. It will be apparent to those skilled in the art that numerous modifications and variations within the scope of the present inventions are possible. For example, the different exemplary electropolishing and electroplating devices, such as the cleaning chamber, the optical sensors, the liquid delivery system, end-point detectors, and the like may be used together in a single process assembly or may be used separately to enhance electropolishing and/or electroplating systems and methods. Accordingly, the present invention is defined by the appended claims and should not be limited by the description herein.